PHOTOPRODUCTION OF NEUTRAL MESONS WITH THE CRYSTAL-BARREL DETECTOR AT ELSA

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The general success of quark models led to the problem of *missing* resonances. Many states predicted by constituent quark model calculations have not been observed experimentally or are only weakly established. This open question is discussed on the basis of experimental results of the CB-ELSA experiment at the e^- accelerator ELSA in Bonn. Differential cross sections of $\gamma\,p \rightarrow p\,\pi^0$ and $\gamma\,p \rightarrow p\,\eta$ are presented for incident photon energies up to $E_\gamma = 3$ GeV. At low energies, results of experiments such as GRAAL and CLAS are reproduced to a good accuracy. New data points have been added for forward angles of the meson and at energies above 2 GeV. In the differential cross sections of both π^0 and η photoproduction, a transition from dominant resonance production to a strong peaking in the forward direction can be observed around $E_\gamma = 2$ GeV. Moreover, total cross sections of $\gamma\,p \rightarrow p\,\pi^0\,\pi^0$ ($\pi^0\eta$) are discussed. Resonance production and even cascades of the type $N^{**}(\Delta^{**}) \rightarrow N^*(\Delta^*) \rightarrow p\pi^0\pi^0(p\pi^0\eta)$ are observed. Indications for at least one Δ resonance around 1900 MeV are seen. The latter would be particularly interesting if it had negative parity because this state would be in contradiction with constituent quark models [1,2].

1. Introduction

Photon-induced reactions on the nucleon are a rich source of information for the baryon resonance spectrum. The full knowledge of possible baryon excitations and their properties would allow the extraction of the relevant degrees of freedom. Spectroscopic predictions are not possible in the non-perturbative regime of QCD. For this reason, effective theories and models are necessary in order to determine the masses, couplings and decay widths of resonances. Various constituent quark models are quite successful in describing the spectra. However, many open questions still remain. All models predict a series of hitherto unobserved states, for instance. The persistent non-observation would be a big problem as those models would

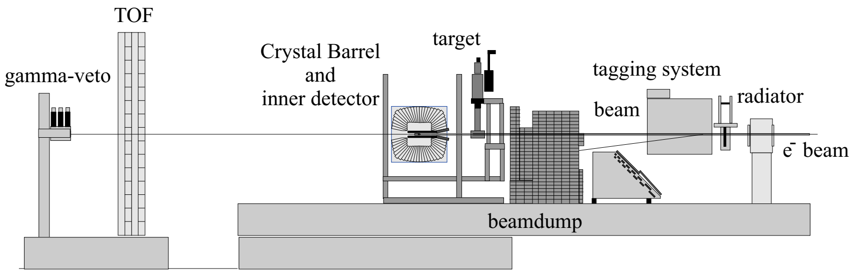

Figure 1. Start configuration for a first series of measurements

have failed to describe physical reality. One explanation is that baryons have a quark-diquark structure. This would reduce the internal number of degrees of freedom and thus, the number of possible baryon resonances. On the other hand, almost all existing data result from πN elastic scattering experiments and models focussing on baryon strong decays predict baryon states to be missing in πN analyses but to show up however in electromagnetic production [3]. Therefore, photoproduction experiments offer a large discovery potential.

The decay chain $\gamma\,\mathrm{p} \to \Delta^* \to (\Delta\,\eta)(\mathrm{I} = \frac{3}{2}) \to \mathrm{p}\,\pi^0\eta$ is a suitable reaction to study Δ states and to search for *missing* Δ^*. Additionally the region of Δ resonances with masses around 1950 MeV is of special interest in baryon spectroscopy. The PDG lists four well established states with positive parity in this mass region. In comparison only three Δ^* with negative parity and poor experimental evidence are listed: $\Delta(1900)\mathrm{S}_{31}$ (**), $\Delta(1940)\mathrm{D}_{33}$ (*) and $\Delta(1930)\mathrm{D}_{35}$ (***). A confirmation of those states with negative parity would be in contradiction with constituent quark models predicting the three states at masses clearly above 2 GeV [1,2].

2. The Crystal-Barrel Experiment at ELSA

The ELSA accelerator complex in Bonn provides electron beams up to energies of 3.5 GeV. A LINAC preaccelerates the particles which are then injected into an electron synchrotron. The latter provides electrons with energies up to 1.6 GeV which are finally transferred to the stretcher ring ELSA.

For the data presented here, electrons extracted from ELSA with energies E_0 hit a primary radiation target and produced bremsstrahlung. The corresponding energy of the photons ($E_\gamma = E_0 - E_{\mathrm{e}^-}$) was determined in a tagging system by the deflection of the scattered electrons in a magnetic field. This detector provided a tagged beam in the photon energy range from 0.8 GeV up to 3.0 GeV for an incoming electron energy of 3.2 GeV. The setup of the CB-ELSA detector used for a first series of experiments is shown in Fig. 1. The calorimeter (Crystal-Barrel) consisting of 1380 CsI(Tl) crystals covering about 98 % of 4π solid angle is an ideal detector for photons. The photoproduction target in the center of the Crystal-Barrel (5 cm in length, 3 cm in diameter) was filled with liquid hydrogen. The target was surrounded by a scintillating fibre detector built to detect and to trigger on charged particles leaving the target (proton trigger). In addition, it provided an intersection point of a particle's trajectory with the detector and hence helped to identify clusters of charged particles in the barrel. The general concept of the experiment is to combine the calorimeter with suitable forward detectors. Besides Time-Of-Flight walls in the start configuration, the TAPS detector (calorimeter consisting of 528 hexagonal BaF_2 crystals) was used in a second series of measurements. The latter

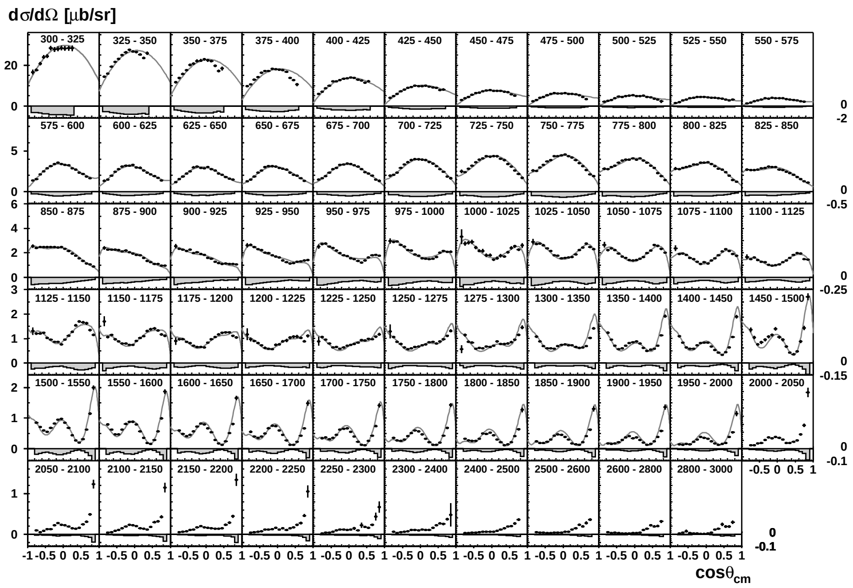

Figure 2. Preliminary differential cross sections for π^0 photoproduction from 300 MeV up to 3.0 GeV. The solid line indicates predictions by the SAID model. Systematic errors are given as grey-shaded area at the bottom of each energy bin. For energies below 1.3 GeV, the photon flux was determined by a χ^2 fit to the SAID predictions. Above 1.3 GeV, normalisation is taken from a measured photon flux scaled by a global factor of 0.75 in order to account for experimental uncertainties.

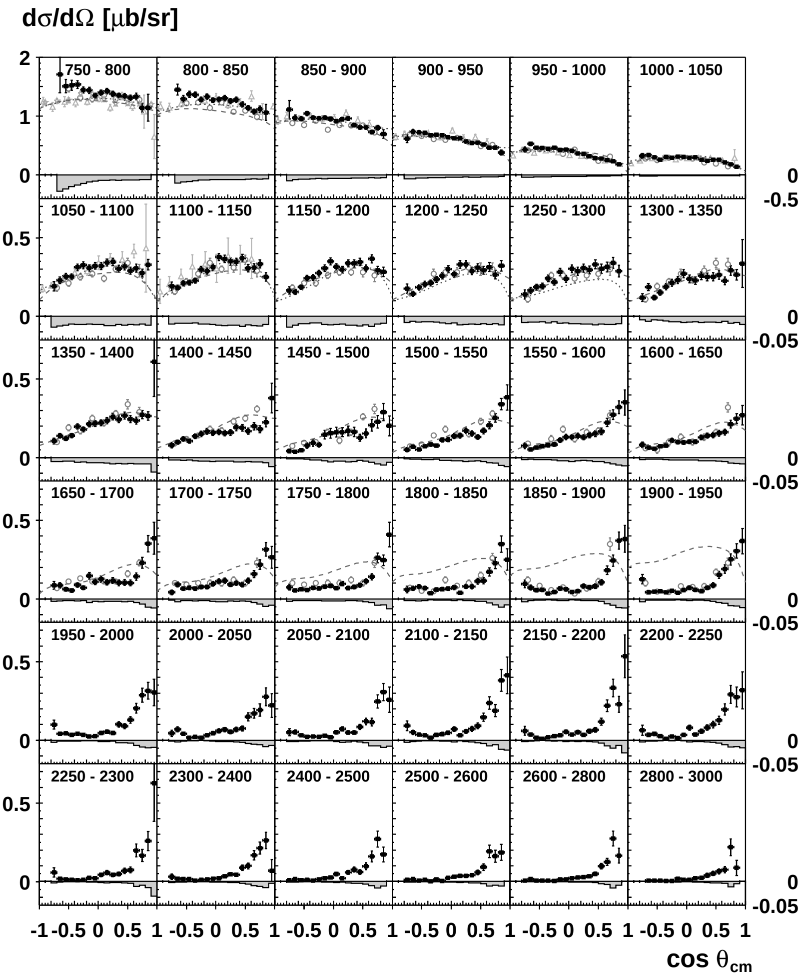

Figure 3. Preliminary differential cross sections for η photoproduction from 750 MeV up to 3.0 GeV. Normalisation is the same as for π^0 production. Systematic errors are given as grey-shaded area at the bottom of each energy bin. Symbols indicate: CB-ELSA (■), TAPS (⋆), CLAS (∘), GRAAL (△), MAID (dotted line), SAID (dashed line).

has fast trigger capabilities and provides high granularity in the forward direction.

Data was taken from December 2000 with the whole apparatus fully operational. Measurements at three different ELSA energies were performed: E_0 =1400, 2600 and 3200 MeV.

3. Investigations of π^0 and η final states

Fig. 2 shows differential cross sections for single π^0 photoproduction. The CB-ELSA results are in excellent agreement with the predictions of the SAID [4] model. The latter is a parametrisation of a large amount of previously measured π^0 data. Towards higher photon energies, i.e. above 2.2 GeV, resonance contributions disappear and a strong forward peaking can be observed. The latter can be described by t-channel exchange of ρ and ω mesons and thus helps to identify resonant contributions. Exploring the high energy part of the spectrum allows extrapolation of t-channel contributions at lower energies.

Photoproduction of η mesons ($I = 0$) serves as an isospin filter because only nucleon resonances can be excited. The preliminary results are given in Fig. 3 and are consistent with measurements from TAPS [5], GRAAL [6,7], CLAS [8] and, for photon energies below 1.5 GeV, with the two models SAID [4] and MAID [9]. The dominance of the $S_{11}(1535)$ can clearly be seen as isotropic behaviour of the differential cross section close to threshold. As in the case of π^0 photoproduction, a transition from resonance production to a strong forward peaking is observed (t-channel exchange). A small rise of the η differential cross section for higher energies in the backward direction of the meson may indicate u-channel contributions.

Fig. 4 shows the high quality of the data. Background subtraction was applied only for the η channel. The background underneath the π^0 signal is very small and, thus, not explicitely treated.

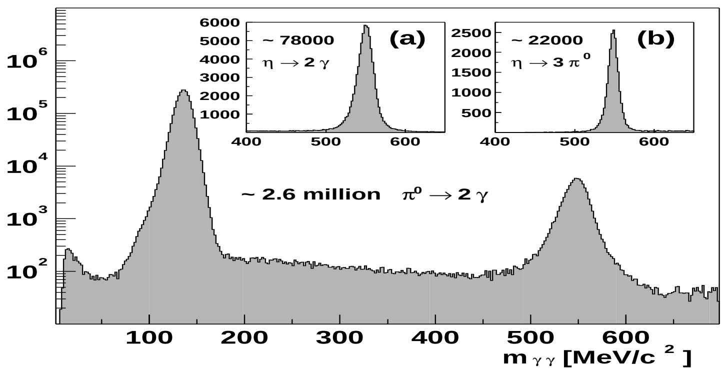

Figure 4. Invariant two-photon mass: (a) $\eta\to\gamma\gamma$, (b) $\eta\to3\pi^0$

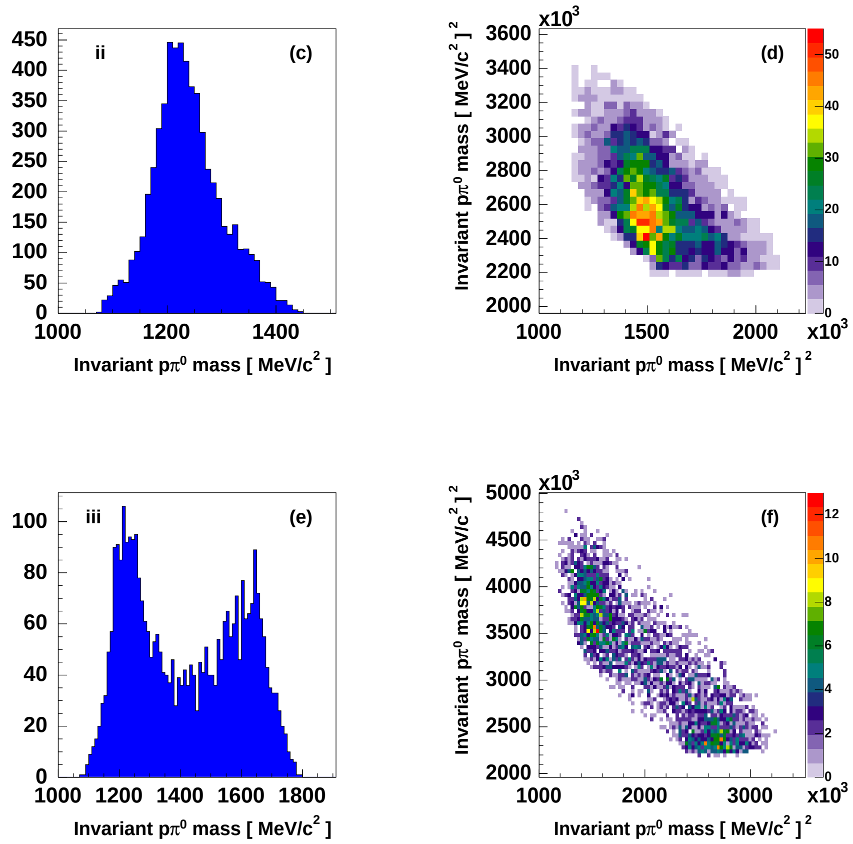

Figure 5. Different plots on the reaction $\gamma\,\mathrm{p} \;\rightarrow\; \mathrm{p}\,\pi^0\,\eta$. See text for details!

4. Preliminary results on the reaction $\gamma\,p \rightarrow p\,\pi^0\,\eta$

In the following, results are presented for a data run at $E_0 = 3.2$ GeV resulting in $\approx 22\,000\ \pi^0\eta$ events. Figure 5 (a) shows the total invariant mass for the $p\,\pi^0\,\eta$ final state. No structures are visible at first sight. Different mass regions are indicated and the corresponding $p\pi^0$ mass spectra given. Hints for baryon resonances decaying into $\Delta\eta$ now become visible. In the total mass region around 1700 MeV, no structure can be seen, Fig. 5 (b). However, a clear peak at the Δ mass can be observed in the mass region around 1900 MeV, Fig. 5 (c). We expect a series of resonances in this mass region with positive as well as with negative parity. In principle, it would be very difficult to disentangle them. However, in the $\Delta\eta$ threshold region we expect a small angular momentum between the η meson and $\Delta(1232)$. Hence, it should be possible to excite some resonances selectively. For orbital angular momenta $l = 0$ or 1, we should expect contributions from the $\Delta(1910)P_{31}$, $\Delta(1920)P_{33}$, $\Delta(1905)F_{35}$ $(l = 1)$ and $\Delta(1940)D_{33}$ $(l = 0)$.

For higher $p\,\pi^0$ masses, further resonance intensity may be hidden in a structure around 1600 MeV, Fig. 5 (e). One has to be careful interpreting structures in the mass projections as those are often reflections of the corresponding Dalitz plots (Fig. 5 (d) and (f)).

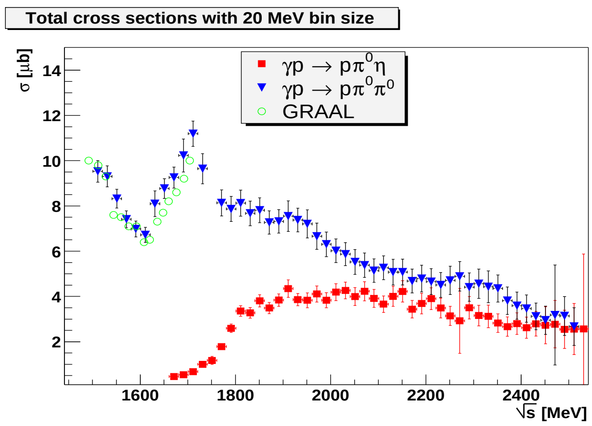

Figure 6. Preliminary total cross sections for $\gamma\,p \rightarrow p\,\pi^0\,\eta$ and $\gamma\,p \rightarrow p\,\pi^0\,\pi^0$. The low-energy part of the CB-ELSA double-pion cross section agrees well with the GRAAL data. It should be mentioned that no proper five-dimensional acceptance correction has been applied yet.

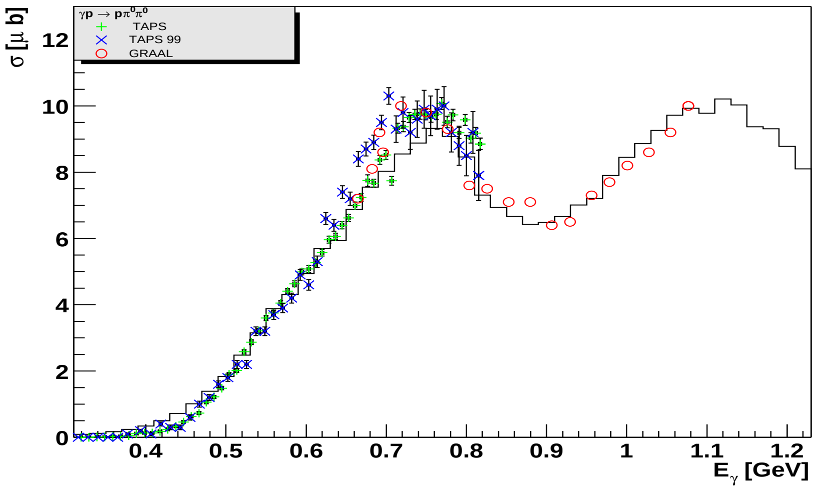

Figure 7. Preliminary total cross section for the reaction $\gamma\,\mathrm{p} \;\to\; \mathrm{p}\,\pi^0\,\pi^0$. The solid line indicates the CB-ELSA PWA result based on a data sample using an incoming ELSA electron energy of $E_0 = 1.4$ GeV. This energy range corresponds to a mass range of 1240 MeV/c^2 - 1900 MeV/c^2.

Fig. 6 shows the total cross sections for the reactions $\gamma\,\mathrm{p} \;\to\; \mathrm{p}\,\pi^0\,\eta$ and $\gamma\,\mathrm{p} \;\to\; \mathrm{p}\,\pi^0\,\pi^0$. The latter agrees very well with the GRAAL data in the low energy region. Above 2 GeV both cross sections are almost equal in magnitude. However, it should be mentioned that no proper five-dimensional acceptance correction has been carried out yet.

Preliminary solutions of a partial wave analysis are based on an unbinned maximum likelihood fit taking all correlations among five independent variables properly into account (event-based fit). New resonances are needed to describe the data. There is evidence for a new Δ state at ≈ 2.2 GeV as well as hints for $\Delta^* \to \mathrm{a}_0(980)\mathrm{p}$ as the dominant contribution for $\mathrm{a}_0(980)$ production. Solutions can be ambiguous and therefore the question of negative-parity Δ states around 1950 MeV cannot be answered yet. Polarisation data is needed to discriminate between different contributing amplitudes.

5. Preliminary results on the reaction $\gamma\,\mathrm{p} \;\to\; \mathrm{p}\,\pi^0\,\pi^0$

Fig. 8 (left side) shows the total invariant mass of the reaction $\gamma\,\mathrm{p} \;\to\; \mathrm{p}\,\pi^0\,\pi^0$ for an ELSA energy of $E_0 = 1.4$ GeV. A clear peak

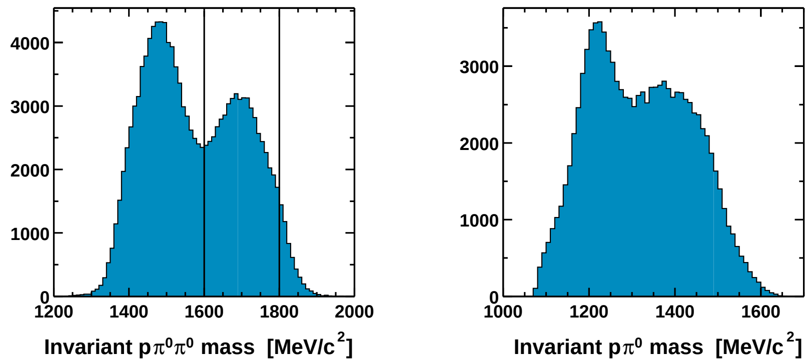

Figure 8. Different plots on the reaction $\gamma\,\mathrm{p} \rightarrow \mathrm{p}\,\pi^0\,\pi^0$. See text for details!

around 1500 MeV/c^2 as well as a structure at 1700 MeV/c^2 can be observed. The right side of Fig. 8 shows the pπ^0 mass for the indicated mass range (1600 MeV/c^2 - 1800 MeV/c^2). Baryon cascades of the type $\mathrm{N}^{**}(\Delta^{**}) \rightarrow \Delta(1232)\pi^0 \rightarrow \mathrm{p}\pi^0\pi^0$ become obvious. A structure at higher masses is also observed.

The preliminary result of an event-based partial wave analysis confirms the parameters of known (***) and (****) resonances in the low-energy spectrum below 1.4 GeV. Dominant contributions are N(1520)D_{13}, Δ(1700)D_{33}, N(1680)F_{15} and N(1720)P_{13}. Contributions of the nucleon resonance N(1700)D_{13} are less dominant.

6. Conclusions and outlook

The good agreement between CB-ELSA π^0 data and predictions by the SAID model shows that the detector acceptance is understood, which forms the basis for partial wave analyses. Furthermore, high quality η data have been measured and differential cross sections determined up to $E_\gamma = 3.0$ GeV. New resonances are in fact needed to describe the data. For example, there is evidence for a new Δ state around 2.2 GeV.

Simulations however, have shown that the mass and angular distributions of a Δ^* resonance ($J^P = 3/2^-$) cannot be distinguished from those of a Δ^* ($J^P = 1/2^+$), at least when interference effects are neglected. The CB/TAPS collaboration has taken data with linearly polarised photons created by coherent bremsstrahlung in a well-oriented diamond crystal. In general the use of linear polarisation breaks the Φ symmetry. Thus,

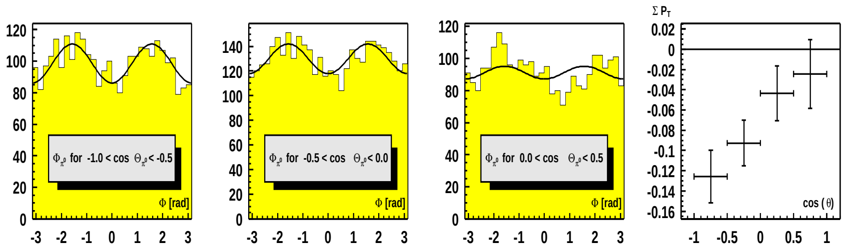

Figure 9. Φ_{π^0} distributions for different Θ_{π^0} bins. The data are not acceptance corrected. The incoming photon energy is limited to 1440 MeV $\leq E_\gamma \leq$ 1640 MeV, i.e. the polarisation maximum.

polarisation allows a better determination of contributing amplitudes by adding further constraints in the PWA, e.g. small contributions may have large effects in certain polarisation variables.

In a two-body decay, the use of linearly polarised photons (polarisation P_T) leads to a photon asymmetry Σ:

$$\sigma = \sigma_0(1 + P_T \cdot \Sigma \cdot \cos(2\Phi))$$

In a three-body final state like $p\pi^0\eta$, there is more than one asymmetry depending on the choice of the corresponding Φ distribution. Fig. 9 shows the first results from a 2003 data-taking period. A photon asymmetry can clearly be extracted from the Φ_{π^0} distribution for different Θ_{π^0} bins, for instance. Even considering only 40 % polarisation and contributions from background processes, statistics should be sufficient to investigate the 1950 MeV/c^2 mass region and contribute to the question of negative-parity states as well as to the problem of *missing* resonances.

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